Seismic Tomography of Maya Pyramid Ruins: Belize, Central America

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Abstract

Two seismic tests have been conducted around Maya pyramid ruins in Belize, Central America in June, 2000 and March 2001. The purpose of the surveys was to test whether a hammer-seismic technique could propagate energy through the carbonate-rubble and mortar pyramids and if this energy could then be used to make images of the interior of the structures. In the 2000 survey, ten 3-component geophones were planted, with 2 m spacing, on one side of an 18m high pyramid at Chan Chich, Belize. Five source points were on an adjacent side of the pyramid – giving a geometry similar to that of a VSP on its side. In the 2001 survey, a 3-component geophone line was laid along the same elevation contour. However, in 2001, there were 27 hammer-sledge sources, as well as 20 geophones, both with 2.5 m spacing. We find that high signal-to-noise first arrivals can be picked on all of the data. First-break arrivals were used from vertical component traces with a traveltime inversion to estimate the velocities inside the pyramid. Velocity contour maps were created with associated resolution and reliability analyses. Inversion results from both vintages of surveys show similar velocity structures. The near-surface of the pyramid has velocities about 200~300 m/s while the interior has higher velocities (500 m/s to 700 m/s). There is evidence of a low velocity region amongst the higher velocity areas.

In 2001, another seismic tomography survey was conducted over a pyramid ruin at Ma'ax Na – farther north in Belize. The inversion results, in this case, again indicate a high-velocity core surrounded by low-velocity materials. We conclude that the hammer-seismic tomography technique can produce good images of the inside of the pyramids and shows considerable promise as an archaeological imaging tool.

Chan Chich 2000 Survey

In June 2000, a hammer-seismic survey around a Maya pyramid ruin was acquired in Belize, Central America at the Chan Chich archaeological site. The carbonate rubble and mortar pyramid has rounded corners and a soft-soil surface covered by tropical jungle. The pyramid is about 40 m by 40 m at the base and stands some 18 m high. A unique seismic dataset was acquired: Five hammer-seismic sources are located on one side of the pyramid, juxtaposed with ten 3-component geophones planted on the adjacent, perpendicular side. The 3-C receivers are spaced along a 2 m contour level, up from the base of the pyramid, and at a 2 m horizontal spacing (atypical geophone layout scene is shown in Figure 1). The shots were spaced a nominal 4 m on the perpendicular side. One shot (#6) is on the same side of the pyramid as the receivers, between receiver #1 and #2. This survey geometry is thus similar to a VSP on its side. Sixty first-arrivals are picked from the 6 shots and 10 receivers.

The sledge-hammer source was struck about 20 times per shot point, and produced a fairly broadband signal from about 5 Hz to 155Hz. We assume straight raypaths and cast the traveltime inversion (tomography problem) as a system of linear equations: $\mathbf{t} = \mathbf{D} \bullet \mathbf{s}$ (where t is the vector of first-break times, D is the matrix of travel paths, and s are the material slownesses) to estimate the velocity structure inside the pyramid. Using 4 m by 4 m pixels, the singular value decomposition (SVD) method is used to solve the inversion. The result is shown in Figure 4.

Chan Chich 2001 Survey

Encouraged by the result of 2000, a second visit was made to the same pyramid in March 2001. This time, a geophone line containing 20 3-component geophones with 2.5 m spacing was laid along the same contour line. The sledge-hammer sources were struck 3 times per shot point. There were 27 shots located at the same elevation of the receiver line, with spacing of 2.5 m. The geometry is shown in Figure 3. Therefore, there are 27x20=540 traces in total. In general, the 2001 data quality is higher than the year 2000 data (partially as a result of a rebuilt geophone cable and less shot stacking). The vertical component (of the three geophone elements) shows best quality as evidenced by clear events and consistent first breaks (Figure 2). The tapped (as opposed to full swing) hammer-seismic source created a broadband signal up to about 200Hz at the 40 dB down level. The inversion result is shown in Figure 3 and Figure 5, where we see a broader coverage, but similar velocity profile to the 2000 result.

Ma'ax Na 2001 data:

Also in the 2001 tests, a tomographic test was conducted on a second pyramid at the Ma'ax Na archaeological site. This pyramid, which is smaller than Chan Chich structure, was about 28 m by 28 m at the base and 15 m high. The 3-component line was wrapped around the front half of the pyramid about 3 m up from the base. Twenty 3-C geophones were again used at a 2.5 m spacing, with hammer shots in the middle of all receivers (on the half-station). We used the first 16 geophones and first 16 shots to perform the traveltime inversion for velocity. As before, the first breaks are picked from the vertical component data. A bin size of 3 m is chosen for the analysis. The resultant velocity map is shown in Figure 6.

Conclusion

We find that the hammer-seismic technique provides excellent energy transmission through two pyramid ruins in Belize. The first-breaking energy can be used to create images of the interior of the structures. Via traveltime inversion (tomography), the 2000 test data at the Chan Chich site, gave a pyramid surface velocity of 200~300 m/s and interior velocities of 500 m/s to 700 m/s. The velocity results from the 2001 tests give similar velocities but with broader coverage. We find velocities at the Ma'ax Na site to have a similar velocity structure: the surficial areas with velocities of 200~300 m/s and a higher-velocity core of about 700 m/s.

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Figure 1. Planting geophones on the side of a pyramid ruin in Belize, Central America.

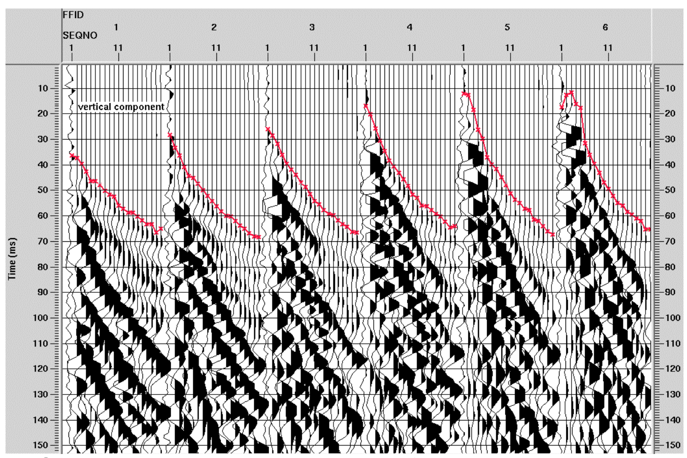

Figure 2. Some Vertical-component traces with first-break picks, year 2001 survey.

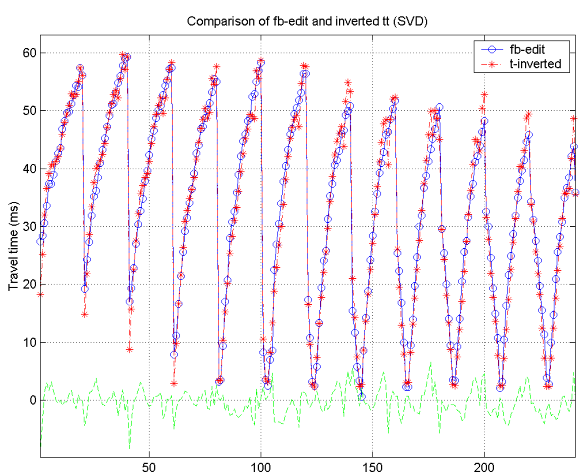

Figure 3. Comparison of the observed first-break time and calculated time from inversion-estimated slowness model, year 2001data.

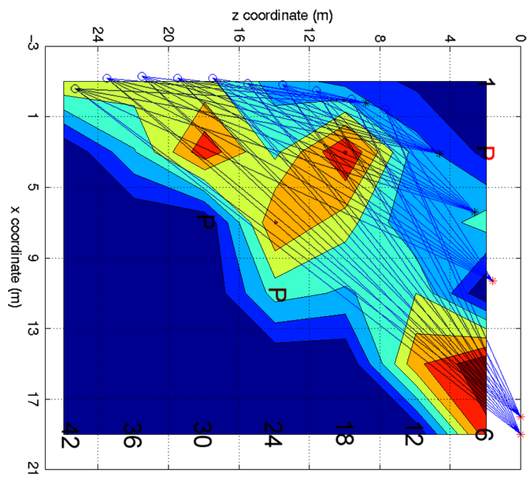

Figure 4. Velocity slice from the 2000 hammer-seismic test around the Chan Chich, Belize pyramid.

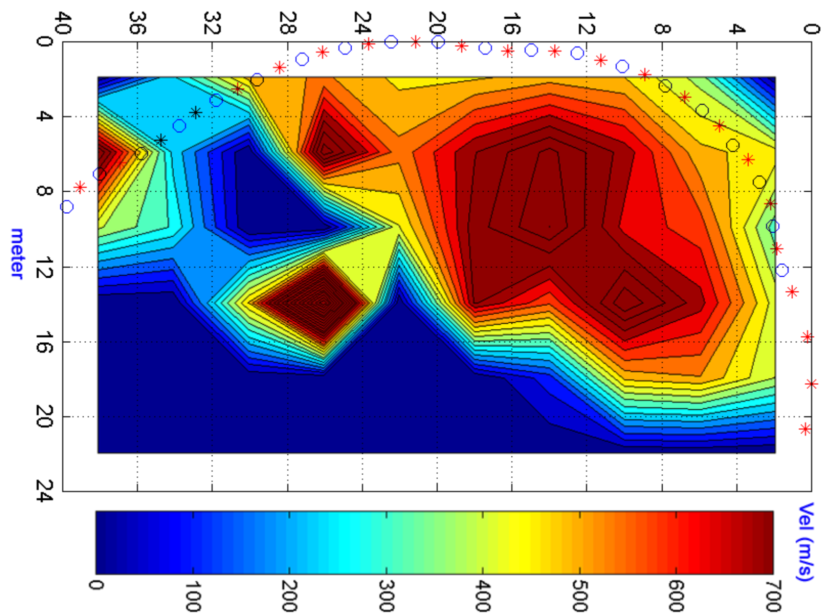

Figure 5. Velocity from the 2001 tests around the Chan Chich, Belize pyramid.

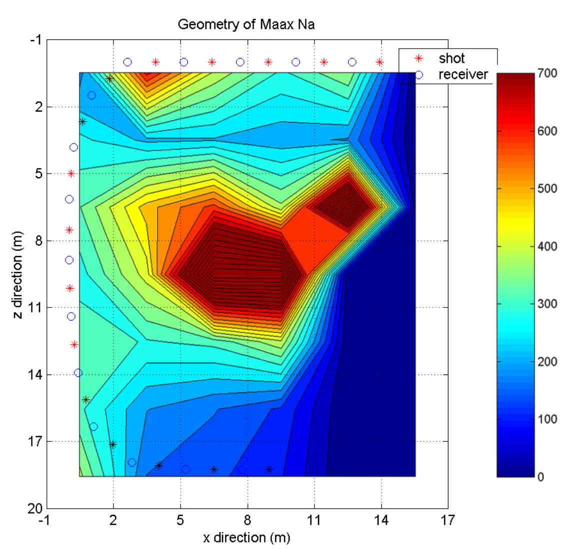

Figure 6. Velocity map of Ma'ax Na, Belize pyramid.

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